METHODS AND APPARATUS FOR FORMING DIAMOND-LIKE COATINGS

An apparatus for depositing a coating onto a surface of a substrate comprising: -a vacuum chamber with an inlet for supplying a precursor gas to the chamber, the chamber comprising, -a carrier for locating the substrate in the chamber, the substrate, when located in the carrier constituting a first cathode; -a first anode having an aperture in which a plasma can be formed, and -a magnetic field source, wherein, in use, a substantially linear magnetic field between the anode and the cathode is formed such that the direction of the magnetic field is substantially orthogonal to the surface to be coated and plasma production and deposition takes place substantially within the linear field.
Description

Methods and Apparatus for forming Diamond-Like Coatings

Technical field

[0001] This invention relates to methods and apparatus for providing coatings on substrates. More specifically the invention relates to using a uniform magnetic field to obtain a coating, such as a diamond-like coating, on a substrate.

Background art

[0002] Carbon can exist in many forms which differ in their physical form and properties, one form is diamond/sp3 carbon. Diamond-like carbon is typically an amorphous form of sp3 carbon and has many of the same properties of diamond, however the material is composed of short order chains rather than the long order chains of natural diamonds. Diamond-like coatings on substrates are used in a range of industries due to their hardness, wear resistance, high conductivity of heat, high degree of chemical inertness and low coefficient of friction.

[0003] A number of methods have been developed to deposit diamond-like coatings on a substrate, these include sputtering processes, ion beam and plasma RF deposition processes, using AC or pulsed DC voltages, using gaseous or solid carbon sources, applying sublayers to the substrate before depositing diamond-like coatings or using composite carbon coatings. Problems with prior art methods are that they are only capable of creating coatings up to 5 microns without flaking. Examples of these methods can be found in WO2005/056869, WO03/078679, WO99/27893, and WO2005/054540. In particular:

[0004] RU2094528 describes a method of sputtering to obtain a diamond-like coating on a substrate. This document discloses pumping hydrocarbon into a chamber comprising two cathodes, an anode and the substrate, where one of the cathodes is a graphite cathode. Carbon atoms are sputtered in all directions, originating from both the hydrocarbon gas and the graphite cathode. This indirect coating method suffers from poor adhesion and deposition rates and poor deposition uniformity occurs when coating larger objects.
RU2095466 describes using an alternating magnetic field, and a hydrocarbon gas as the sole carbon source to deposit a diamond-like coating directly onto the substrate. This method allowed larger and circular objects to be coated and increased the deposition rate of the coating, however due to the non-linear magnetic field a non-uniform magnetic field is created and therefore an even coating is not obtained.

RU2105082 discloses a two step method comprising applying a sublayer to the substrate before applying the diamond-like coating. Applying a sublayer to the substrate before depositing a diamond-like coating increased the adhesion for the diamond-like coating. The document describes placing Ti cathodes between the anode and the object to be coated to sputter Ti onto the surface of the substrate to be coated. Once the sublayer is formed the Ti cathode voltage is changed to become an anode and stop sputtering, hydrocarbon gas is then introduced to form the diamond-like coating on the substrate. However the Ti electrode interferes with the plasma flow during the diamond-like coating step causing poor deposition rates and uneven coatings are obtained, especially on larger articles.

The invention proposes creating a linear magnetic field between a cathode and an anode such that the hydrocarbon plasma is in a substantially linear field, to deposit a diamond-like coating directly onto the substrate. Using a uniform magnetic field means a more uniform diamond-like coating can be applied to the substrate, and larger objects can be coated.

Disclosure of the invention

One aspect of the invention provides an apparatus for depositing a coating onto a substrate comprising, a vacuum chamber with an inlet for supplying a precursor gas to the chamber, the chamber comprising, a carrier for locating the substrate in the chamber, the substrate, when located in the carrier constituting a first cathode; a first anode having an aperture in which plasma can be formed; and, a magnetic field source, wherein, in use a substantially linear magnetic field between the anode and the cathode is formed such that the direction of the magnetic field is substantially
orthogonal to the surface to be coated and plasma production and deposition takes place substantially within the linear magnetic field. Maintaining the plasma within the magnetic field allows for better control of the plasma therefore better deposition and adhesion. Using a linear magnetic field that is orthogonal to the surface to be coated, such that the plasma is produced from the precursor gas in the orthogonal field, to deposit a coating on a substrate provides a more even coating on the substrate. The precursor gas is selected such that it comprises the ions from which the plasma will be created from. Such as a hydrocarbon gas for applying a diamond-like coating, or a silane gas for a silicon based coating.

[0009] Preferably the anode has a non-circular aperture. The anode can be various shapes depending on the substrate to be coated however a square or rectangular shape is preferred. A non-circular anode allows for a more even coating as it reduces the focusing of the plasma.

[0010] Preferably the anode has an aperture with a depth:width aspect ratio greater than 1:2. More preferably the aspect ratio is greater than 1:50. An aspect ratio of at least this dimension reduces the focusing of the plasma and thereby allowing a more even coating to be obtained. The aspect ratio can be in the range of 1:2 to 1:3000 and will depend on the object that is to be coated.

[0011] Preferably the apparatus comprises a DC bias voltage supply. Preferably the voltage supply is an unpulsed DC bias voltage supply.

[0012] The magnetic field source can comprise a first and a second magnet located adjacent to the cathode and the anode. Preferably these magnets are permanent magnets.

[0013] The magnets can be connected by a magnetic conductor such that opposite poles are presented at the cathode and anode. One of the cathode or anode will have a magnetic north polarity with the other of the cathode or anode having a south polarity. Having opposite poles for the electrodes helps create a substantially uniform magnetic field. The magnetic field can be further intensified if a soft iron type magnetic conductor is used.
[0014] Preferably the substrate is able to rotate relative to the anode. The apparatus can be used to coat a wide variety of different shapes including the inner surfaces of enclosed objects and the outer surfaces of curved objects, such as pipes. In order to coat different areas of the outer surface of a substrate the apparatus is configured so that the substrate is rotated relative to the anode to ensure the entire outer surface to be coated comes in contact with the magnetic field and plasma and therefore is coated.

[0015] The vacuum chamber can additionally contain a sputter ion pump for the deposition of a sublayer on the substrate. The sputter ion pump can comprise an anode and two cathodes wherein at least one of the cathodes comprise the material to form the sublayer. Preferably a titanium cathode is used, however magnesium, aluminium and beryllium can also be used. Applying a sublayer to the substrate before applying a diamond-like coating, can increase the adhesion of the coating to the substrate. However if the substrate to be coated is titanium, aluminium or magnesium preferably a sublayer is not used. Preferably the apparatus comprises a first zone in the vacuum chamber for the deposition of a sublayer and a second zone for depositing the coating on the substrate. The carrier can be movable between the first and second zones. Having distinct areas in the chamber for performing the two processes allows separate anode and cathode arrangements to be used for each process and therefore plasma flow and control to be optimised for applying a sublayer and applying the coating.

[0016] Alternatively the vacuum chamber can additionally comprise an inlet to introduce a gas containing the sublayer metals. Using gases containing the sublayer materials allows for a more even sublayer to be applied. An even sublayer is important because the sublayer is not very thick and it helps to ensure that an even diamond-like coating can then be formed.

[0017] In one embodiment of the invention the anode can be located within the substrate, for depositing a diamond-like coating onto an inner surface of a substrate. The inner surface of objects, such as pipes can be coated using the apparatus. Preferably the apparatus is configured such that the
substrate can rotate relative to the anode. This can allow the entire inside cavity of an object to be coated.

[0018] In another embodiment the apparatus comprises, a second anode located on the opposite side of the substrate from the first cathode for depositing a coating on at least two opposite surfaces of a substrate, wherein, in use, a plasma is produced at each of the anodes. This allows two sides of an object to be coated at substantially the same time, such as two outer surfaces of an object or an inner and an outer surface of the object.

[0019] An apparatus can comprise a second cathode, such that the anode is located between the first and second cathodes and linear magnetic field is formed between the first and second cathodes.

[0020] A second aspect of the invention is a method for depositing a coating onto a substrate in a vacuum chamber comprising, creating a substantially linear magnetic field between a first cathode, defined by the substrate and a first anode having an aperture in which a plasma can be formed, wherein the magnetic field is substantially orthogonal to the surface of the substrate; supplying a precursor gas into the chamber; creating a plasma from the gas within the linear magnetic field at the aperture of the anode; controlling the plasma within the magnetic field; and depositing a coating onto the substrate within the linear magnetic field. As the plasma is charged it will be directed towards the substrate surface due to the voltage difference of the anode and substrate. In the plasma deposition method controlling the plasma within a magnetic field orthogonal to the surface allows for better control of the plasma as it is deposited onto the surface of the substrate.

[0021] Preferably the method comprises using an anode that has a non-circular aperture. An anode that has a width:depth aspect ratio greater than 1:2, preferably an aspect ratio greater than 1:50 is used.

[0022] Preferably the method comprises supplying a hydrocarbon carbon gas as the precursor gas. Using a hydrocarbon gas allows a diamond-like coating to be applied to the substrate.
[0023] Preferably the process is carried out at a temperature of less than 200°C. More preferably the process is operated at a temperature of less than 140°C.

[0024] The method comprises applying a DC bias voltage to create the plasma. Preferably an unpulsed DC bias voltage is applied to create the plasma.

[0025] Preferably the method comprises depositing a sublayer on the surface of the substrate before the coating is deposited onto the substrate. However if the substrate is made from a material that can be used as a sublayer, such as titanium, aluminium or magnesium, then a sublayer is not needed.

[0026] A sputter ion pump located in the chamber can be used to deposit the sublayer. Titanium, magnesium, aluminium or beryllium cathodes can be used in the sputter ion pump to form the sublayer, preferably titanium.

[0027] Preferably the method comprises depositing a sublayer in a first zone of the chamber and then depositing the coating in a second zone of the chamber. The substrate can be located on a carrier which is movable between the first and second zones.

[0028] Alternatively the sublayer is deposited by introducing a gas containing the sublayer material into the chamber, before introducing the hydrocarbon gas into the chamber. The gas forms a plasma at the anode which is accelerated towards the substrate by the electric field and is deposited directly onto the surface of the substrate.

[0029] In one embodiment the method comprises; placing the first anode inside the substrate to be coated to deposit a coating onto an inner surface of the object to be coated

[0030] In another embodiment the method can comprise creating the substantially linear field between the first anode, the first cathode and a second anode for depositing a coating onto two surfaces of a substrate in a vacuum chamber wherein the cathode is located between the first and second anodes.

[0031] The method can be carried out to deposit a coating greater than 5 microns.

[0032] It is preferred that the methods are performed using the apparatus as described above.
Brief description of the drawings

[0033] Figure 1 shows a schematic of the apparatus for applying a coating to a substrate;
Figure 2 shows a schematic view of part of the apparatus of the invention for applying a coating to the inner surface of objects; and
Figure 3 shows a schematic view of an apparatus for applying a sublayer and coating to the substrate; and
Figure 4 shows a schematic view of an apparatus for applying a sublayer and a coating to the outer surface of a circular object.
Figure 5 shows a schematic view of an apparatus for applying a sublayer and a coating to two surfaces of a substrate.
Figure 6 shows a schematic view of an apparatus for applying a sublayer and coating to the outer surface of a circular object.
Figure 7 shows a schematic view of an alternative apparatus for applying a sublayer to the substrate.

Mode(s) for carrying out the invention

[0034] With reference to Figure 1 a vacuum chamber 5 comprises a first cathode 7 and an anode 3 for applying a diamond-like coating on a substrate 8. The substrate 8 to be coated acts as a second cathode and is located on a carrier 6. Both the first cathode 7 and the substrate 8 carry permanent magnets such that one has a north polarity and the other has as a south polarity to produce a uniform linear magnetic field B, between the first cathode 7 and the substrate 8. The cathode 7 and substrate 8 are at ground potential while the anode 3 has a positive potential. The chamber further comprises an inlet for an etching gas 1, an inlet for hydrocarbon gas 2, and a port for evacuation of the vacuum chamber 4.

[0035] A diamond-like coating is deposited on the substrate by first evacuating the chamber via the port 4. A helium leak detector can be used to ensure a good vacuum is obtained. An inert etching gas is introduced into the chamber via the inlet 1. Krypton is the preferred etching gas, however neon and argon can also be used. Once etching is complete the supply of
the inert gas is stopped and the hydrocarbon gas is introduced into the chamber via the second inlet 2. A hydrocarbon plasma is formed in the aperture of the anode 3, using a DC bias voltage that is not pulsed, and carbon atoms are directly deposited onto the surface of the substrate 8. As the substrate 8 lies between the magnets and has the opposite polarity of the first cathode 7 a uniform magnetic field B is created which runs through the substrate 8 in a very linear uniform fashion controlling the plasma ions in the linear field as they are directed towards the substrate from the anode allowing for an even coating to be obtained on the substrate. The magnetic field is preferably in the range of 10-200mT, and the hydrocarbon plasma deposition preferably occurs using a voltage 0.5-4.5KV. This higher voltage helps makes the plasma more stable. The strength of the magnetic field and voltage will depend upon factors such as anode size, field strength, pressures and hydrocarbon. The plasma is formed in the linear magnetic field between the anode and the substrate. Therefore the plasma is maintained in a linear magnetic field between the point of production and deposition. Producing the plasma ions in a linear magnetic field allows better control over the deposition of the atoms and improved uniformity of the coating on the substrate.

[0036] It is preferred that permanent magnets are used when coating a flat surface, as they create a straight linear field. It is easier to make a field that is orthogonal to the substrate with permanent magnets than with electromagnets. The permanent magnets are located behind the cathodes. The use of opposite polarities for the cathode 7 and substrate 8, as well as creating a uniform magnetic field, increases the plasma flow and therefore the deposition rate. This was surprising as it was expected that a more turbulent magnetic field, such as that created by having alternating polarity of the cathodes, would be better for increasing plasma deposition rates, due to more focal points for collisions of atoms causing them dissociate.

[0037] The aspect ratio of the aperture of the anode is greater than 1:2 (aperture depth:width). Preferably greater than 1:50. An aspect ratio of 1:3000 can be used and the aspect ratio used can depend on the size of the object.
being coated. This is quite different from that used in similar arrangements such as Penning cells/ion pumps, which generally use an anode with an aperture having depth:width aspect ratio of around 1:1 to 1:2. The larger aspect ratio reduces the focusing of the plasma on the substrate so allows for a more even coating to be obtained. The anode aperture is preferably non-circular and preferably is a square or rectangular shape.

[0038] A second anode may be placed on the opposite side of the substrate from where the first anode is situated. This can allow both sides of a substrate to be coated.

[0039] Figure 2 shows an embodiment of the invention for coating the inside cavity of objects. Inside a vacuum chamber an anode 21 is located inside the substrate of which the inner surface 22 needs coating. Magnets are situated outside the substrate and a magnetic circuit produces a uniform magnetic field whose direction is substantially orthogonal to the surface to be coated. The substrate acts as a cathode and is rotated relative to the anode 21. The diamond-like coating is produced as described above by introducing hydrocarbon gas into the chamber. A hydrocarbon plasma is formed at the aperture 23 of the anode and a uniform magnetic field B controls it towards the inner surface 22 of the substrate, while the substrate is rotated relative to the anode, to form a coating on the inner surface 22.

[0040] Figure 3 shows one embodiment of the invention able to apply a sublayer to the substrate before a diamond-like coating is applied. A vacuum chamber 36 comprises a sputter ion pump for sputtering sublayer metal ions onto the surface of the substrate. The sputter ion pump comprises two cathodes 37, 39 and a first anode 38, one of the cathode being the metal which the sublayer is to comprise, preferably the cathode is titanium, however it may also be magnesium or aluminium. A magnetic field B is formed between the cathodes. The substrate 311 to be coated is located on a carrier 31 and is initially positioned in a first zone 312 of the chamber parallel to the magnetic field B. A plasma is created from a gas at the first anode 38. The ions are accelerated towards the titanium cathodes 37 by the magnetic field B, this sputters titanium ions away from the cathode
surface which can hit and bind to the surface of the substrate 311 located in the first zone 312. The sublayer can be applied at a lower vacuum than previously used of 5x10^-3Pa up to 1x10^4Pa achieved by evacuating the chamber via port 35. The optimal thickness for the sublayer is around 0.01 microns thickness, however this can depend upon the application and the substrate being coated.

[0041] Once the sublayer is formed the movable carrier 31 transfers the substrate 311 to be coated to a second zone of the chamber, where the substrate 311 will act as a cathode. Here the vacuum chamber 6 comprises a second anode 34 placed between the substrate 311 and a further cathode 310 whereby a uniform magnetic field B orthogonal to the surface of the substrate 311 is created due to the magnets located adjacent to the cathode 310 and substrate 311. The diamond like-coating is applied as described above for Figure 1, with an etching gas being introduced via an inlet 32, and then subsequently a hydrocarbon gas via an inlet 33. A hydrocarbon plasma is created at the second anode 34 and is directed towards the substrate 311 to be deposited on its surface to form a diamond-like coating. While both figures 1 and 3 exemplify an embodiment wherein the apparatus comprises one anode and two cathodes for depositing the coating. The apparatus can just comprise one cathode, which is the substrate, and an anode, with the linear magnetic field formed between the cathode and anode.

[0042] An embodiment of the invention for applying a sublayer and diamond like coating to the outer surface of a substrate is shown in figure 4. A vacuum chamber 46 comprises a sputter ion pump for sputtering a sublayer metal onto the outer surface of the substrate. The sputter ion pump comprises two cathodes 48 and a first anode 49, with one of the cathodes being the metal for which the sublayer is to comprise. A magnetic field B is formed between the cathodes. The substrate to be coated 43 is located on a carrier and is initially positioned in a first zone 47 of the chamber. A plasma is created from a gas at the first anode 49 and the ions are accelerated towards to the cathodes and this sputters the metal ions away from the cathode surface which can hit and bind the surface of the
substrate 43 located in the first zone 47. The substrate is rotated as the sublayer is being applied to allow the whole outer surface of the object to be coated. Once the sublayer is formed a movable carrier transfers the substrate 43 to a second zone of the chamber, where the substrate will act as a cathode. The vacuum chamber comprises a second anode 45 and a magnetic source to produce a uniform magnetic field between the substrate 43 at the first zone and the anode 45, whose direction is substantially orthogonal to the surface to be coated is created. The diamond like coating is applied as described above, wherein the chamber is evacuated via port 44, an etching gas in introduced via an inlet 41, and then subsequently a hydrocarbon gas via an inlet 42. A hydrocarbon plasma is created at the second anode 45 and is directed towards the substrate 43 in a linear manner to be deposited on its surface. The substrate is rotated as the hydrocarbon plasma is deposited on its surface so that a diamond-like coating is applied to the whole outer surface of the curved object.

[0043] Whilst both figures 3 and 4 demonstrate an embodiment of the invention whereby the substrate is moved between the ion sputter pump and the second anode, it is also possible to have an arrangement whereby the substrate is stationary and the sputter ion pump and second anode are movable. First a sputter ion pump arrangement is moved into position in the vacuum chamber to apply a sublayer to the substrate. Once the sublayer has been applied the sputter ion pump arrangement is moved and the second anode is moved into place such that a uniform magnetic field whose direction is substantially orthogonal to the surface to be coated can be produced. The substrate will acts as a cathode and a diamond-like coating is deposited onto the substrate.

[0044] Figure 5 shows an embodiment of the invention for applying a sublayer and a diamond like coating to two surfaces of an object. A vacuum chamber 56 comprises two anodes 53, 58 and a substrate 57 on a carrier 54. The substrate 57 acts as a cathode and is positioned in between the two anodes 53, 58, such the surfaces of the substrate to be coated are each facing an anode 53, 58. A magnetic source (not shown) produces a
uniform magnetic field B between the anodes with the substrate to be coated in the middle. The diamond-like coating is deposited as described above. An etching gas is introduced to the chamber via an inlet 51, and then the hydrocarbon gas via an inlet port 52, the chamber also comprises a port 55 for evacuation of the vacuum chamber. A hydrocarbon plasma is formed at each of the anodes 53, 58 and the magnetic field B maintains the hydrocarbon plasmas in the linear magnetic field as the plasma is directed towards each surface of the substrate 57 to be coated, thereby resulting in both surfaces of the substrate being coated simultaneously. A sublayer can be first applied to both surfaces of the substrate. This occurs by a similar arrangement as described in Figure 3. To coat two surfaces of the substrate the vacuum chamber 56 comprises two sputter ion pumps each comprising an anode 511, 512 and a pair of cathodes 510, 513, one of each of the pairs of cathodes being the metal which the sublayer is to comprise. The substrate 57 is located on a carrier 54 and is initially positioned in a first zone 59 of the chamber between the two sputter ion pumps. A magnetic field B is formed between each of the pairs of cathodes. A plasma is created from a gas in the chamber at each of the anodes 511, 152 forming the sputter ion pumps. The ions accelerate towards the cathodes, this sputters metal ions away from the cathodes and towards the substrate surfaces which they can hit and bind. As there are two sputter ion pumps present in the chamber, both sides of the substrate can have a sublayer applied at the same time. Once the sublayer is applied the movable carrier 54 transfer the substrate from the first zone to a second zone in the chamber where the substrate 57 will act as a cathode and is in between the two anodes for depositing a diamond-like coating on the surfaces of the substrate.

[0045] A similar arrangement can be used to apply a sublayer and a diamond-like coating to the outer surface of a circular object as shown in Figure 6. A vacuum chamber 66 comprises two sputter ion pump arrangements each comprising a pair of cathodes 69, 612 and an anode 610, 611. A substrate 64 is initially located on a movable carrier in a first zone 68 of the chamber in between the two sputter ion pumps. A magnetic field B is formed
between each of the pairs of cathodes. A plasma is created from a gas introduced into the chamber at each of the anodes 611, 610 forming the sputter ion pumps. The ions are accelerated towards the cathodes, this sputters metal ions away from the cathode towards the surface of the substrate, which they can hit and bind. The substrate rotates as the sublayer is being applied.

[0046] Once the sublayer is applied, the movable carrier transfers the substrate 64 from the first zone to a second zone in the chamber where the substrate 64 will act as a cathode. The substrate is in between two anodes 63, 67 for depositing a diamond-like coating on the surfaces of the substrate. A magnetic source (not shown) produces a uniform magnetic field B between the anodes 63, 67 and the substrate 64. The diamond-like coating is deposited as described above. An etching gas is introduced to the chamber via an inlet 61 and then the hydrocarbon gas via an inlet port 62, the chamber also comprises a port 65 for evacuation of the vacuum chamber. A hydrocarbon plasma is formed at each of the anodes 63, 67 and is maintained within the magnetic field B as it is directed towards the surface of the substrate 64 to be coated, thereby resulting in two surface area of the substrate being coated simultaneously. As the diamond-like coating is being applied the substrate will rotate so that the entire outer surface of the circular object will be coated.

[0047] Figure 7 shows another embodiment of the invention for applying a sublayer to a substrate 79 located on a carrier 77 before applying a diamond like coating using a gas containing the sublayer material. The vacuum chamber 76 comprises an inlet for the sublayer gas 71, an inlet for the hydrocarbon gas 73, inlet for etching gas 72 and a port for evacuation of the vacuum chamber 75. The sublayer gas can contain aluminium, titanium or magnesium, but preferably titanium. The chamber 46 comprises a cathode 78, an anode 74 and the substrate 79 which acts as a second cathode. The sublayer is applied by introducing the gas via the inlet 71 to the chamber 76. A plasma is formed at the anode 74 and the plasma is accelerated towards the substrate 79 in a uniform magnetic field B. This directly forms a sublayer on the substrate 79. The supply of the
sublayer gas is stopped and the diamond-like coating is applied as described above using a hydrocarbon gas. A hydrocarbon gas is introduced into the chamber via its inlet 73. A hydrocarbon plasma is formed at the anode 74 and directed towards the substrate 79 while in a uniform magnetic field, directly depositing a diamond-like coating onto the substrate surface.

[0048] Temperature control is also important for good deposition of the coating. Temperature can be controlled by controlling the current which controls the heat generation. By configuring the apparatus so that heat is taken away from the substrate to be coated a higher rate of deposition at a higher current can be obtained.

[0049] An advantage of the present invention is that the process can be carried out at temperatures <140°C. If the article to be coated has previously undergone hardness or heat treatment work, having to use higher temperature to apply the diamond like coating could interfere with this previous work. This especially important when coating steels, where temperatures of 120-160°C can be the start range for affecting the crystal structure of the metals. Most prior art methods are carried out at high temperatures above 200°C, but this can lead to internal stress and cracking of the coating particularly when the trying to increase the thickness of the coating. By carrying out the deposition at lower temperatures it helps prevent the development of internal stress in the coatings. The apparatus of the invention able to achieve thick coating under 200°C, whereby previously only thin coatings coating have been achieved using temperatures below 200°C.

[0050] Using the apparatus and method of the invention for coating a substrate allows thickness of greater than 100 microns to be obtained, depending on the substrate, and a hardness of above 4000HV. This is surprising as coatings using previous methods typically do not obtain diamond-like coatings greater than about 2-5 microns as the coatings tend to disadhere from the surface as the coating becomes thicker. However the process of the invention is able to achieve coatings of greater than 50 microns. A coefficient of friction of about 0.07-0.08 against dry steel or as low as 0.035
against itself at a high surface pressure (>3GPa) can be obtained. The thicker coating enables an unusual, but valuable combination of high load bearing with low coefficient of friction.

[0051] Although the description exemplifies the apparatus for depositing a diamond-like coating the apparatus can be used to produce other coatings on a substrate, i.e. silicon based coatings such as silane.

[0052] Changes may be made while still remaining within the scope of the invention.
Claims

1. An apparatus for depositing a coating onto a surface of a substrate comprising:
   - a vacuum chamber with an inlet for supplying a precursor gas to the chamber, the chamber comprising,
   - a carrier for locating the substrate in the chamber, the substrate, when located in the carrier constituting a first cathode;
   - a first anode having an aperture in which a plasma can be formed, and
   - a magnetic field source,
   wherein, in use, a substantially linear magnetic field between the anode and the cathode is formed such that the direction of the magnetic field is substantially orthogonal to the surface to be coated and plasma production and deposition takes place substantially within the linear field.

2. An apparatus according to claim 1, wherein the anode has a non-circular aperture.

3. An apparatus according to claims 1 or 2, wherein the anode has an aperture with a depth:width aspect ratio greater than 1:2.

4. An apparatus according to claims 1, 2, or 3 comprising a DC bias voltage supply.

5. An apparatus according to any of claims 1-4 comprising an unpulsed DC bias voltage supply.

6. An apparatus according to any of claims 1-5 wherein the magnetic field source comprises first and second magnets located adjacent the cathode and the anode.

7. An apparatus according to any of claims 1-6 wherein the magnets are permanent magnets.
8. The apparatus according to any of claims 1-7, wherein the substrate is able to rotate relative to the anode.

9. An apparatus according to any of claims 1-8, wherein the chamber also comprises a sputter ion pump for the deposition of a sublayer on the substrate.

10. An apparatus according to any of claims 1-9 comprising a first zone for deposition of a sub-layer and a second zone for deposition of the coating.

11. An apparatus according to claim 10 wherein the carrier is moveable between the first zone and the second zone.

12. An apparatus according to any of claims 1-11 wherein the chamber also comprises an inlet for introducing a sublayer gas into the chamber.

13. An apparatus according to any of claims 1-12 wherein the anode can be located within the substrate for depositing a coating on the inner surface of the substrate.

14. An apparatus according to any of claims 1-13 comprising a second anode located on the opposite side of the substrate from the first anode for depositing a coating onto at least two opposite surfaces of a substrate wherein, in use, a plasma is produced at each of the anodes.

15. An apparatus according to any of claims 1-14 comprising a second cathode such that the anode is located between the first and second cathode and the linear magnetic field is formed between the first and second cathodes.

16. A method for depositing a coating onto a substrate in a vacuum chamber comprising,
creating a substantially linear magnetic field between a first cathode defined by the substrate and a first anode having an anode in which a plasma can be
formed, wherein the magnetic field is substantially orthogonal to the surface of the substrate;

supplying a precursor gas into the chamber;

creating a plasma from the gas within the linear magnetic field at the aperture of the anode;

controlling the plasma within the magnetic field; and

depositing a coating onto the substrate within the linear magnetic field.

17. A method according to claim 16, comprising using an anode that has non-circular aperture.

18. A method according to claims 16 or 17, comprising using an anode that has an aperture with a depth: width aspect ratio greater than 1:2.

19. A method according to any of claims 16-18 comprising supplying a hydrocarbon gas as the precursor gas.

20. A method according to any of claims 16-19 wherein the process is carried out at a temperature of less than 200°C.

21. A method according to any of claims 16-20 comprising applying a DC bias voltage to create the plasma.

22. A method according to any of claims 16-21 comprising applying an unpulsed DC bias voltage to create the plasma.

23. A method according to any of claims 16-22 comprising rotating the substrate relative to the anode to coat the surface of the substrate.

24. A method according to any of claims 16-23 comprising depositing a sublayer on the surface of the substrate before depositing the coating onto the substrate.
25. A method according to claim 24, comprising using a sputter ion pump located in the chamber to apply the sublayer.

26. A method according to claims 24 or 25, comprising depositing a sublayer in a first zone of the chamber and then depositing the coating in a second zone of the chamber.

27. A method according to claim 24, comprising introducing a gas containing the sublayer material into the chamber, which will form a plasma and deposit a sublayer directly onto the surface of the substrate, before introducing the precursor gas into the chamber to deposit the coating.

28. A method according to any of claims 16-27 comprising placing the first anode inside the substrate to be coated to deposit a coating onto an inner surface of the substrate.

29. A method according to any of claims 16-27 comprising creating the substantially linear field between the first anode, the first cathode and a second anode to deposit a coating onto two surfaces of a substrate in a vacuum chamber.

30. A method according to any of claims 16-29 when carried out for depositing a coating greater than 5 microns.

31. A method according to any of claims 16-30 when performed using an apparatus according to any one of claims 1-15.

32. A product produced by a method according to anyone of claims 16-31.